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Solid – State Current Limiting Star – Delta Starter for A 3-Phase Squirrel Cage Induction Motor

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Abstract

The high starting current of a squirrel cage induction motor is undesirable. A solid state current limiting star – delta starter have been proposed and implemented. The circuit consist of a microcontroller, optocouplers and power TRIAC. The microcontroller and optocouplers produces the electrical signal that turn ON the power TRIAC. The power TRIAC are arranged such that they can automatically connect the winding of an induction motor in star mode and after a preset time the motor is switch to delta connection. On testing with a 2kW motor, the starting current was limited to 8.2A in star from about 20.2A and when it switches to delta the current increases to 3.2A from a steady value of 0.4A. The result indicates that the design can be implemented in higher power rated squirrel cage induction motors

1.0 Introduction

Induction motors are the most commonly used electric drives, about 90% of industrial electric drives are induction motors [1]. There are two main types of induction motors, they differ based on their rotor design. They are the squirrel cage rotor and Wound rotor induction motors [2]. The stator winding of both types of induction motors are polyphase windings. In the squirrel cage rotor, the active part of the rotor are a number of copper or aluminium bars that run from one end of the rotor core to the other, they are short circuited at both ends by end rings. In the wound rotor type, a balanced distributed windings of a definite number of pole as the stator winding are wound on the rotor slots and the winding are connected to an external circuit through slip rings [3]. One of the main characteristic of a squirrel cage induction motors is the high inrush current it draws during starting. The starting current is about 5 to 7 times the full load current [4]. The rotor current is expressed in Equation (1) [3]. The starting current is very high because of the low impedance of the copper conductors and on starting, the slip = 1.

$$I_r = \frac{s.E_r}{\sqrt{R_r^2 + sX_r^2}} \quad (1)$$

where:
s is the slip,
E_r is the induce emf in the rotor circuit,
R_r is the resistance of the rotor conductor and
X_r is the reactance of the rotor conductor.
The inrush or high starting current in induction motor causes a dip (sag) in voltage [5]. Generally, to minimize voltage dip, a current limiting starter is necessary. The starters for starting induction motors includes: direct on line starter, auto-transformers starter, star/delta starter, resistance starter and solid state soft starter [3, 6]. Direct on line starter is cheap, simple and is suitable for electric motors with star or delta connections. However, it does not prevent voltage dip due to high starting or inrush current. They are used for low to medium power induction motors because starting current limitation in these range of induction motors is not necessary. For induction motors of higher power rating, other methods of starting are utilized. [7]. The use of the auto-transformer makes it possible to decide the value of starting current while supplying a reduced voltage to the motor during starting. The motor is initially connected to the desired auto-transformer tapings for reduced voltage, when the current has falls to a safer value, the motor is connected to its full voltage rating [3]. In the star – delta method of starting induction motors, the motor starts on star and changes to delta automatically after a preset time. Because the motor starts on star, the voltage in the induction motor winding at starting, is the phase voltage which is 1/√3 or 57.7% of the line voltage, the starting current is reduced to 1/3 or 0.33% of the full load current while the starting torque is one-third of the rated toque on delta-connection. The star – delta starting is realized with the use of contactors and a relay timer [3, 8]. In the use of resistance starter, three resistors or inductors of suitable values are connected in series with each phases of the stator windings. As the motor accelerates to its optimal speed, the resistors/inductors are disconnected and the motor windings are then connected directly to the supply. The major drawback of the resistance starter is that the stating torque is very poor [3]. The solid state soft starter is gaining popularity in recent time. The soft starter circuit consist of two silicon control rectifiers (SCRs) connected in parallel with each phases of the supply to the induction motor. The solid – state soft starters operates smoothly, the acceleration time, torque and current can be adjusted easily. However, harmonics can be introduce to the supply which can cause interference [9].

The aim of this work is to realize a solid state starter that is based on the principle and the circuitry of the contactor type star delta starter by replacing the contactors with electronic switches.

2. Methodology

The design stages consist of the power supply circuit, control circuit and the Power Drive Star – delta Circuit. The various stages of the design are as follows:

2.1. Power Supply

The power supply circuit consist of a single phase transformer, a bridge rectifier, a capacitor filter and a 7805 voltage regulator for a stabilized voltage output. The power supply circuit supplies a 5V power to the control circuitry.

2.2. Control Circuit

The control circuit consist of a microcontroller, optocouplers and transistors. The microcontroller sends the drive instructions to each of the three sets of transistor/optocoupler drivers. The control sequencer is based on the ATmega328P mounted on Arduino Uno board. The flowchart of the control code for the microcontroller is shown in Figure 1.

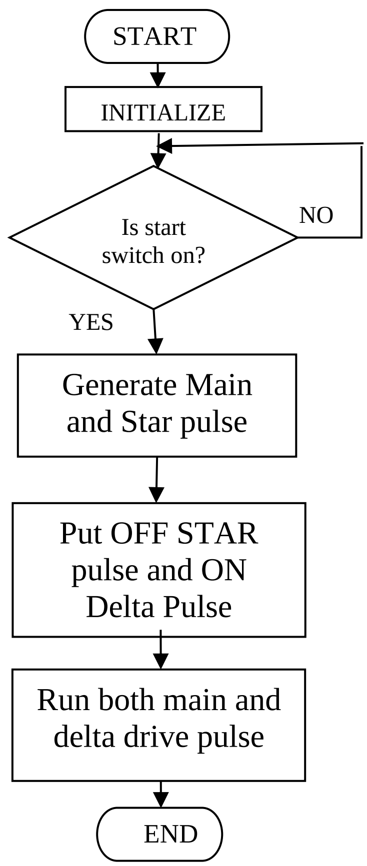

Figure 1. Flowchart for ATMEGA328P control sequencer codes

The optocoupler serve as a switch for the power TRIAC circuit. In order to control an AC current, the photo – TRIAC MOC3021 was selected. The MOC3021 is shown in Figure 2, it comprises of a light emitting diode LED and a TRIAC.

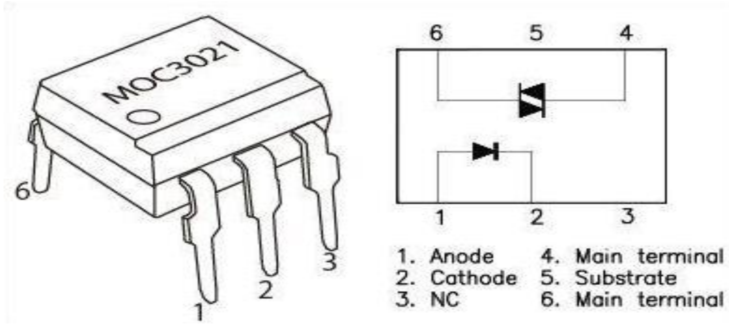

Figure 2 MOC3021 Optocoupler Layout

In this design, the specification of the optocoupler circuit components are as follows:

The LED drive current $(L_{FT}) = 20mA,$

LED voltage drop $(V_d) = 2V$ and

TRIAC drive current = 300mA.

Therefore, the limiting resistor value was obtained as:

$$R = \frac{V_s - V_s}{I_{FT}} \tag{2}$$

where:

Vs is the supply voltage = 5V

$$R = \frac{5-2}{20 \times 10^{-3}} = 150\Omega$$

For the transistor, the collector current $(I_C) = 20mA$ and gain $(\beta) = 100$

The Base (I_B) current is given as [10]:

$$I_B = \frac{I_C}{\beta} \tag{3}$$

$$I_B = \frac{20 \times 10^{-3}}{100} = 200\mu A$$

The base resistor (R_b) is given as:

$$R_b = \frac{V_{mc} - V_{be}}{I_E} \tag{4}$$

where:

V_{mc} is the microcontroller logic high voltage (measured) = 3.5V and

V_{be} is transistor base-emitter region voltage drop = 0.7V

$$R_b = \frac{3.5 - 0.7}{20 \times 10^{-6}} = 14k\Omega$$

A base resistor of 12kΩ was selected as the nearest available standard resistor.

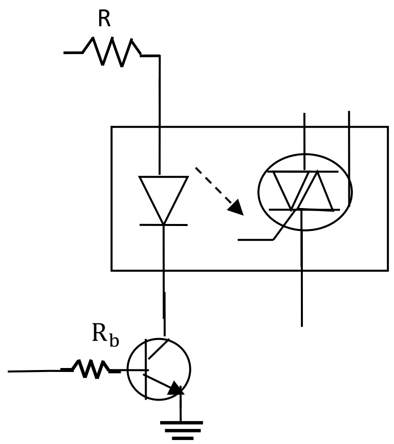

Figure 3. Optocoupler/Transistor circuit

2.3. Power Drive Star – delta Circuit

The power drive circuit is made up of nine power TRIAC BTA-41 arranged such that a star – delta arrangement can be achieved. One set of three TRIAC, connects the electric motor terminals U_1 V_1 and W_1 to the 3 – phase power supply and serves as the main switch, while terminals U_2 V_2 and W_2 are connected through two sets of three TRIAC such that a set of three TRIAC connects the terminal U_2 V_2 and W_2 in star while the other set of three TRIAC connects terminals U_2 V_2 and W_2 to terminals U_1 V_1 and W_1 in delta mode. The optocoupler circuit turn on the Power TRIAC based on the coded instruction from the microcontroller. The TRIAC controlling terminals U_2 V_2 and W_2 in star and delta mode are not activated at the same time. The time delay between the star and delta mode is preset within the coded instructions. A single power TRIAC driver is shown in Figure 4.

The optocoupler circuit is connected to the power TRIAC through a current limiting resistor (R_L) as expressed in Equation 6.

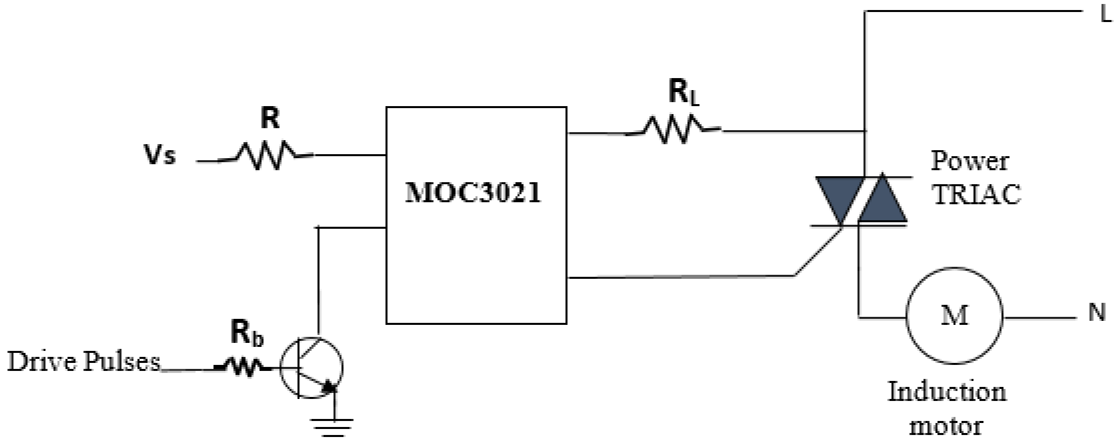

Figure 4. Single Power TRIAC Driver

$$R_L = \frac{V_{max}}{I_{max}} \tag{6}$$

where:

V_{max} is the maximum load voltage and

I_{max} is the maximum trigger current

the maximum load voltage and maximum trigger current are 240V and 360mA respectively.

$$R_L = \frac{240}{360 \times 10^{-3}} = 666.7\Omega$$

A load resistance of 680Ω was selected based on availability.

The complete circuit diagram of the solid – state, star – delta starter is presented in Figures 5 and 6. Figure 5 is the control circuitry consisting of the power supply circuit, microcontroller and optocoupler circuits. For the main control, ma, ma', mb, mb' mc, mc' represents the control circuit of the power TRIAC supplying power to the electric motor terminals U_1 V_1 and W_1. While sa, sa', sb, sb' sc, sc' and da, da', db, db' dc, dc' are the control circuits of the power TRIAC that is connecting the terminals U_2 V_2 and W_2 in star or in delta mode with U_1 V_1 and W_1. Figure 6 is the TRIAC Star – Delta Starter Circuit

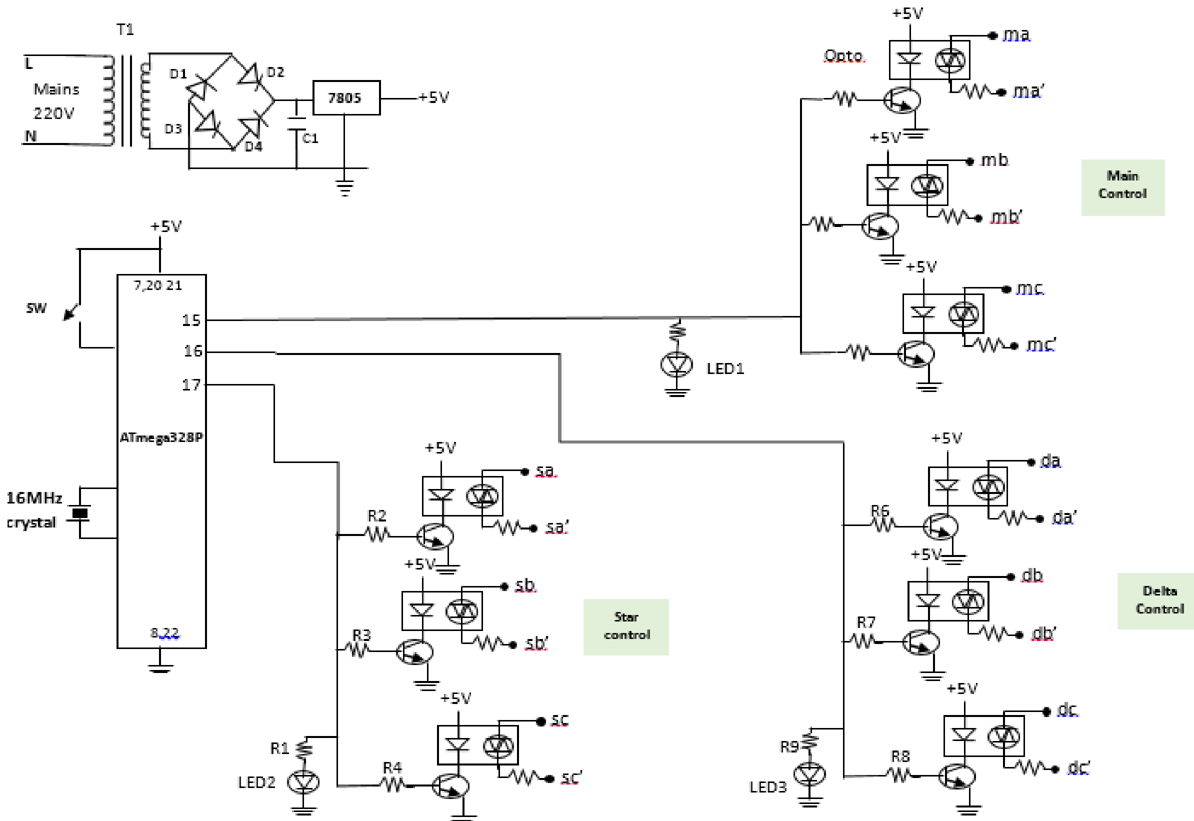

Figure 5: Star-Delta starter Control Circuitry

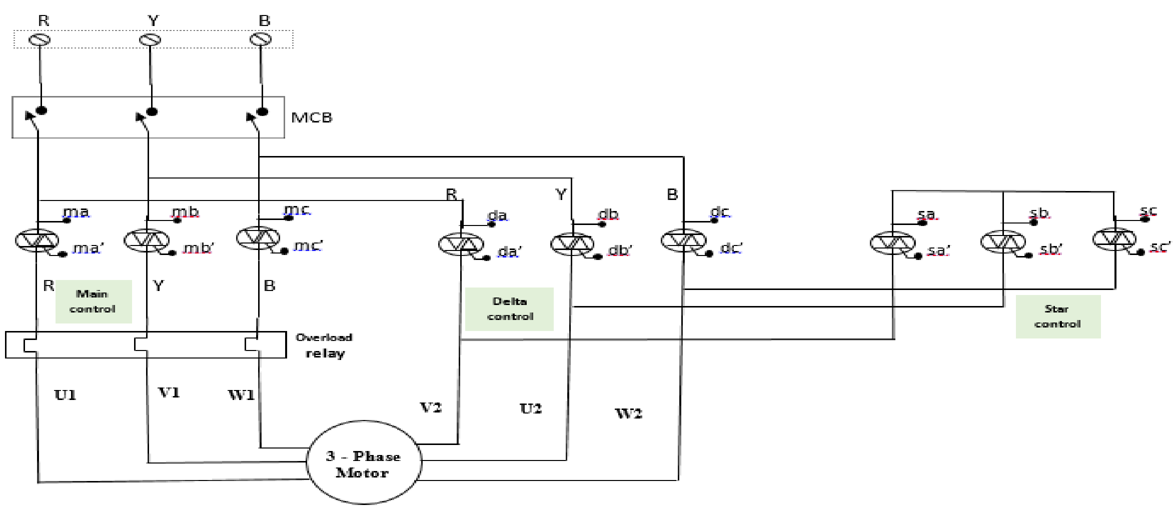

Figure 6: power TRIAC Star – Delta Starter Circuit

3. Implementation, Testing and Results

The star – delta circuit design was implemented on a circuit board as shown in Figure 7.

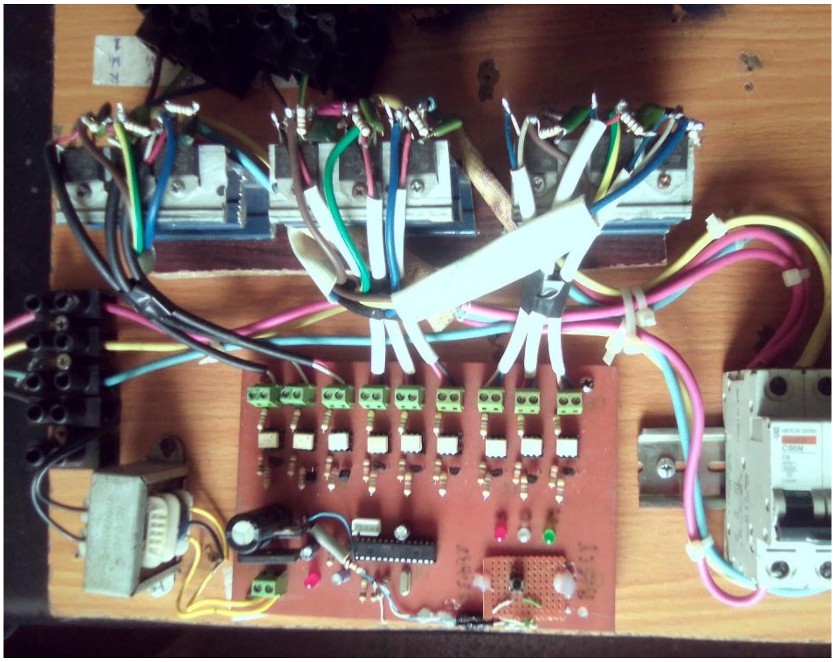

Figure7: Pictorial view of the implemented Solid state star – delta starter

The starter was tested on an electric motor with the following specification: 2kW, 380V, 4.6A. The starting current would be about 5 x 4.4A = 20.2A if the starting current is assumed to be 5 time the full load current, when connected directly in delta mode. The test results when tested on the solid state star – delta starter are shown in Table 1.

Table 1: Starting current of an induction motor with the star – Delta starter.

Connection		I_R **(A)**	I_Y **(A)**	I_B **(A)**
Star – γ	Starting Current	8.2	8.2	8.2
	Steady Current	0.4	0.4	0.4
Delta – Δ	Starting Current	3.2	3.2	3.2
	Steady Current	1.2	1.2	1.2

The squirrel cage rotor drew 8.2A during starting on star and increases slightly to 3.2A when it changes to delta. The current drawn if it were connected directly to supply on delta connection was reduce from about 20.2A to 8.2 on star mode and 3. 2A on delta mode. The results obtained agrees with the theory of star delta starting technique in squirrel cage induction motor as highlighted in literatures in the introductory section.

4. Conclusion

A solid state current limiting star – delta starter have been developed using microcontroller, optocouplers and a power TRIAC. The test results show that current limitation was achieved which is essential for a squirrel cage motor. The obvious advantages of the solid state starter are its compactness, light weight and the elimination of arcing that is common with electromechanical switches.

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